IADIS International Journal on Computer Science and Information Systems
Vol. 9, No. 2, pp. 1-18
ISSN: 1646-3692

DEVELOPMENT STRATEGY OF AN ARCHITECTURE FOR E-HEALTH PERSONALISED SERVICE ROBOTS

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ABSTRACT

This paper presents a service robot architecture based on the principles of a Service-Oriented Architecture (SOA), whose modularity design maximizes the benefits of multidisciplinary contributions from researchers of different areas. The diagram of the proposed architecture is presented and discussed in terms of its development strategy, oriented towards the creation of societal and economical impact. Services are supported by an intelligently managed database, storing personal profiles and preferences towards an active and personalized assistive care. The Entity-Relationship schema is described in detail, giving an overview of how the different types of information are related, e.g., relating preferred activities with specific locations and with preferred friends to take part. It is virtually impossible to identify all elderly needs in advance, since their fragile condition leads to constantly changing needs. The proposed methodology fosters services adaptability. It allows for them to continuously fit elderly specific needs efficiently and improve the quality of a service without requiring redeveloping it entirely. By applying the proposed architecture, a service robot can, for example, actively search for an elderly person to assess his/her status (felling sad, bored, etc.) and perform specific actions in a personalised manner, according to his/her preferences. This work is developed within the context of the Social Robot project, funded by the FP7 Marie Curie Programme IAAP.

KEYWORDS

Service Robot, Elderly Care, Development Architecture, Behaviour Perception, Information Database.

1. INTRODUCTION

This paper presents a service development strategy for a mobile social robot. The main goal is the continuous proactive provision of personalized assistance to elderly people, towards improving their quality of life and independence [Christophorou et al, 2012]. The proposed schema is supported by an intelligently managed database of user profiles and preferences, promoting thus personalized care provision. Population ageing is a problem that the world is currently facing. It is motivating research efforts towards the creation of technologies which are able to continuously assist and support elderly people in their daily lives, and also increasingly making use of different contextual information [Menezes, Quintas and Dias, 2014]. The Ambient Assisted Living (AAL) research area is dominated by service providing technologies, in which the scope of this work is developed.

Robotics and ICT technologies are being taken up by the market as health and social care profitable solutions in terms of deliverance and efficiency [Broek, Cavallo and Wehrmann, 2010]. Using robotic technologies to improve monitoring and assistive services has been target of keen research by different groups and with a strong support of the European Commission. In fact, the EU funded different specific research programmes, such as the Ambient Assisted Living – Joint Programme (AAL-JP), amongst others. One key research branch has been the development of mobile robotic platforms for care assistance and monitoring. Such study covers all the aspects of service provision, from the technological considerations to the end-user feedback, so as to measure the acceptability and requirements of these systems. Some examples of these projects are MOBISERV [Mobiserv, 2009], which developed a robot to support the daily living of seniors focusing on health, nutrition, well-being and safety, including the capability to monitor vital signs or detecting falls. The KSERA [Ksera, 2010] aimed assisting elderly with Chronic Obstructive Pulmonary Disease through monitoring their psychological, behavioural and environmental data and providing embedded entertainment. FLORENCE [Florence, 2010] aimed to improve the well-being of the elderly by providing connectivity, reminders, fall detection, encouraging activities, gamming and interface with some home devices. Notable technological mentions on the field of assistive service robots are the Care-O-Bot [Care-O-Bot] and the Robot Maid [Robot-Maid].

Let us take a closer look over two specific service robots for elderly care that we believe to be good representatives of the current state of the art in AAL and that were developed within the European Research projects, the Companionable [Companionable, 2008] and the Echord – Astromobile [Astromobile, 2011]. Hector was developed within the FP7 Companionable project. Some of its care support services include diary management, memoire services (e.g., reminders for taking medicines on time) and social networking communication. It encompasses a fall detection capability, which the system can use to detect emergencies. Hector can assist a remote control centre to assess the gravity of the fall so that an appropriate action or emergency team is needed. This remote control centre is supervised by humans, which benefit from this awareness to optimize their resources. Simon, on the other hand, has been developed within the FP7 Echord-Astromobile project [Cavallo et al., 2013]. This robot also interacts with users in an indoor environment, with the purpose of assisting them in their daily life or working activities. It uses natural speech recognition, for which they exploit the Open Source Speech-Recognition Software Simon. Originally, Simon was developed to deal with persons suffering from physical disabilities but whose speech capabilities were intact. Some of the supported services include medicine delivery, stand support, reminder alerts and entertainment. Its design integrates a smart environment for better localization services.

A common characteristic of these (and most service robots) is that they are pre-programmed with specific services and knowledge at the manufacturing stage. Consequently they fail to properly exploit the rapid technological advances and also to cope with the constantly changing needs of elderly people. Because of this fast time-to-market oriented strategy, these technologies, as products, will become obsolete in the sense that new products with new capabilities will be available at an increasingly faster pace. What if these technologies could continuously profit from new capabilities through a modular architecture, allowing a seamless integration of new modules? This would create social and economic impact. From a societal perspective, a user could expand an existing platform with new functions, knowledge and services to continuously meet its needs. Economically speaking, buying a technological solution that could be expanded, without having high replacement costs or even buying a new one, presents a clear economic benefit. This manuscript presents a development oriented architecture, which is strategically designed with these two targets as its driving pillars. The proposed architecture was developed and applied within the Social Robot project [Socialrobot, 2012], towards the design and development a mobile platform [Alvito, Marques and Carriço, 2014] for personalized care provision [Christophorou, Tsiourti and Christodoulou, 2014].

2. SOCIALROBOT SYSTEM ARCHITECTURE

2.1 Definitions

The proposed strategy intends to provide a scalable framework through seamless plug and play integration. We propose a hierarchical approach where complex servicing tasks are recursively broken down into simpler operations. For its multidisciplinary oriented development, the following paragraphs introduce four key definitions, which are loosely adapted from the SOA concept of *functionality* to *application* (which in our architecture the latter stands for/represents a *Service*).

Method *A method is a low level process of basic complexity, which operates over the raw data or interacts, through a driver, with peripherals such as input/output devices or databases.*

Function *A function is a self contained unit combining two or more methods. It provides a set of logical operations that are too complex to be considered a method. They are categorized into Robotic, ICT and Behaviour Analysis.*

Service *A service relates to the SOA concept of application in the sense that it orchestrates two or more functions, generating a process where the robot actively interacts with a user and whose main purpose is to assist him, fulfilling an expectation.*

Scenario *A scenario corresponds to an event or sequence of events where the robot provides one or more services to an end user, so as to fulfil a given contextual goal or goals.*

From the definitions, it is easy to understand that methods correspond to the lowest level computational processes and that functions depend on these methods to provide answers to problems of additional complexity. These functions alone do not directly fulfil a user expectation, yet some of them are relevant in the sense that they have the ability to gather the required information used to promote an empathic and personalized experience. In the proposed architecture, there are two key conceptual differences between a function and a service. (1) **A service has to be explicitly experienced by the user**, which means that it should be provided by the platform in order to fulfil an expectation from the user side, for example reminding a user about its personal daily activity schedule and recognizing who the user is, are two complex problems. However, unlike the first, the recognition does not fulfil an expectation on its own, yet it provides the needed identity information such that the system can automatically retrieve the correct person's agenda. Thus, (2) **a service is an orchestration of two or more functions**, requiring performing different operations at different levels, such as communication through output devices or intelligent management information in the database.

2.2 Elements

The development strategy for the design of SocialRobot architecture is based on the concepts of a SOA. The proposed SOA-based meta-model is presented in Figure 1. The following paragraphs describe the different abstraction layers and associated components.

Hardware	*It is composed of physical components corresponding to the input/output technologies available on the mobile platform. For an immersive interactive experience, they include Touch Screen, Display, VoIP, Sound Speakers, Microphones and Video Cameras (RGB-D and simple RGB). These are complemented with a Laser Range Finder and a Sonar array for autonomous navigation purposes.*
Operational	*This layer contains methods which require low-level capability procedures to perform their objectives. It includes modules for basic data processing, querying data from sensors, forwarding data to output devices, a clock and parameter parsing.*
Functional	*The functional layer includes algorithms with decision-making and cognitive reasoning capabilities. Action, person and emotion recognition, navigation with obstacle avoidance, selecting the appropriate information to display or establishing communication are some examples. The main purpose is to assist with the discovery of information needs, provide an adequate solution and intelligently manage information.*
Workflow Engine	*The workflow engine is responsible for the interpretation of a service and orchestrating a sequence of required functionalities to fulfil the associated expectation for that service. It may include a failsafe module, which is responsible to determine alternative solutions in case of an error from the functional layer.*
Service	*The service level is designed so as to allow non developers to define new services themselves. It holds XML format descriptions of a service, which are defined as a sequence of functional modules adequate to assist an elderly. The main categories are Care & Wellness, Guidance and Mobility Monitoring.*

Database *The database is a key element in our framework. It is a knowledge repository containing organized personal information, including user preferences, event and medicine calendar, behaviour profiles and Virtual Care Teams (VCTs). A VCT is a list of associated family members, caregivers, friends or neighbours which constitute a social pool for contacting in case of emergency or socialization purposes.*

The proposed architecture is illustrated in Figure 1. The hierarchical abstraction layers and modules clearly represent the definitions that have been previously introduced. To promote scalability, inter-layer communication is minimized, such that it is limited to adjacent layers, *e.g., functional processes can only access the hardware via the operational methods*. Such approach mitigates functional dependencies, reducing the scalability problem to a local and simpler challenge of interacting with adjacent layers using a standardized set of inputs and outputs.

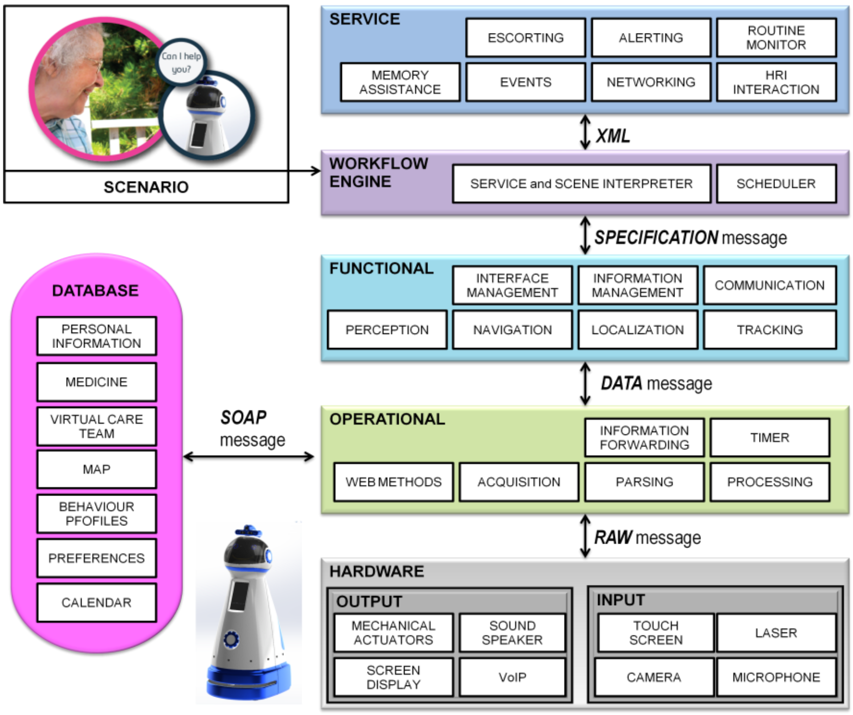

Figure 1. Social Robot Architecture

A natural consequence is that communication between adjacent modules is confined to specific abstraction levels. For example, raw messages contain data suitable to be used from or by the hardware level, while Specification messages contain sets of parameters that are used as function inputs or to control the workflow engine execution. The architecture is supported by different frameworks. The Robotic Operating System (ROS) is the supporting framework located at the robotic platform. The SoCo-net uses a Microsoft SQL Server and a set of Java Web-Methods that are exposed via web services. Communication between both frameworks is ensured by SOAP-based messages and standard web communication protocols. However, alternative frameworks may be used. This architecture aims to establish a clear separation between service design and low-level development. The following paragraphs discuss how the proposed design can address the two initially identified objectives.

2.3 Services and Workflow Engine

Unlike other service robot solutions, the SocialRobot architecture offers an intuitive XML-based service orchestration, minimizing the need for expert developer intervention. To define a service, there is only the need to select functional requirements and specify a set of intuitive parameters, such as its execution order. An example of such definition is depicted in Figure 2, where it is visible the simplicity with which a service may be defined.

```
<Service>
    <ServiceName>Skype Call</ServiceName>
    <Description>Robot goes to elderly room to make a daily call to a friend via skype.</Description>
    <Function>
        <Name>Navigation to Person's Room</Name> //Includes Tracking Algorithms
        <Callback>Navigate_To</Callback>
        <Order>1</Order>
        <Mandatory>True</Mandatory>
        <Preemptive>True</Preemptive>
    </Function>
    <Function>
        <Name>Face Recognition</Name>
        <Callback>Face_Recognition</Callback>
        <Order>2</Order>
        <Mandatory>True</Mandatory>
        <Preemptive>False</Preemptive>
        <Dependencies>Navigate_To</Dependencies> //Only starts after navigation concludes
    </Function>
    <Function>
        <Name>Skype</Name>
        <Callback>Skype_Call</Callback>
        <Order>3</Order>
        <Mandatory>True</Mandatory>
        <Preemptive>False</Preemptive>
        <Dependencies>Face_Recognition</Dependencies> //Requires positive recognition to locate data from SoCo-net
    </Function>
</Service>
```

Figure 2. Example of a service XML definition, as is used as the input in the system.

During the first stage of a service interpretation, the workflow engine is responsible to assess service integrity, which means it has to verify that the functional sequence meets input/output requirements. The different steps of the engine are presented in Algorithm 1.

At step 2 of the presented Algorithm 1, the engine executes a verification stage of the functional parameters with two key purposes: 1) check for service integrity, i.e. it mainly ensures that all functions exist and are running on the platform, and also that all data requirements will be met during service execution by cross-checking the functional inputs and outputs; 2) assign flags according to the parameters of each function, such that execution complies with the defined service rules. The following paragraphs introduce the implemented parameters known by the engine and how they are interpreted while executing a sequence of different functions.

Order *Functions may need to be executed in a specific order, this parameter defines such order.*

Mandatory *Some functions are mandatory while some may not be. For example, there might be different functions to recognize a person which may run concurrently, for example, recognizing people by their voice or their face. In these cases, when a concurrent function reaches its goal, it stops the other concurrent functions.*

Preemptive *This parameter gives a function the ability to stop other functions, issuing a signal when it finishes its execution. An example is given of two functions that might need to use the same hardware resources. Preemptiveness is given to priority functions.*

Dependencies *The "dependencies" parameter identifies if the function depends on information coming from other functions, and only executes after all dependencies have finished their jobs and published the required information.*

Preemptiveness and Mandatory flags are parameters that may be used to identify potential alternative solutions in case of functional errors. Let us assume that if a given function is flagged as being preemptive but not mandatory, it means that the system is redundant, such that it is equipped with two or more functions that are capable of performing the same goal. Hence, these two flags become a relevant feature to consider when scaling the system with the failsafe module.

Algorithm 1. The pseudo-code that represents the different steps used by the work flow engine to execute a service.

Workflow Engine Runtime Steps

```
Input   Service XML file
        PARSE service to functional sequence
        VERIFY function parameters and ensure service integrity
        Try
            for 1:n such that n=number of required service call back functions do
                request input data;
                execute function; /* At the for cycle we can combine any functions we see fit to
                fulfil a goal. */
                process output data;
            end for
        end try
        catch exception
            report fail log and do
                Repeat
                Or
                alert Virtual Care Team member and enter sleep mode
            end and
        end try
        if sequence=success then
            wait new service request;
        end if
Output  Scenario status
```

2.4 SoCo-Net: An Intelligently Managed Database

The Social care Community network (SoCo-net) [Christophorou et al, 2012a] constitutes another core component of the SocialRobot solution. It is an elderly centric, web-based virtual collaborative social community network that enables the effective administration and coordination of the user (Person) profiles and VCTs around the elderly person (see Figure 3).

A VCT consists of people (members) of different ages (young and old) and roles (relatives, friends, neighbours, care professionals, etc.) that can assist, collaborate and actively communicate with the elderly. SoCo-net services' main objective is to ensure that the elderly, through the ageing process, will have a unique personalized profile of disabilities and abilities, special needs and preferences thus promoting personalized care provision. In order to promote modularity, the SoCo-net components and schema are designed, developed and maintained independently from the robotic platform. Information management, at the current development stage, is mainly maintained by *VCT* members, which have the ultimate responsibility of ensuring data correctness. However, from the robot's perspective, there are already implemented methods responsible for retrieving and storing the required data for service provision and, when necessary, update the database table contents.

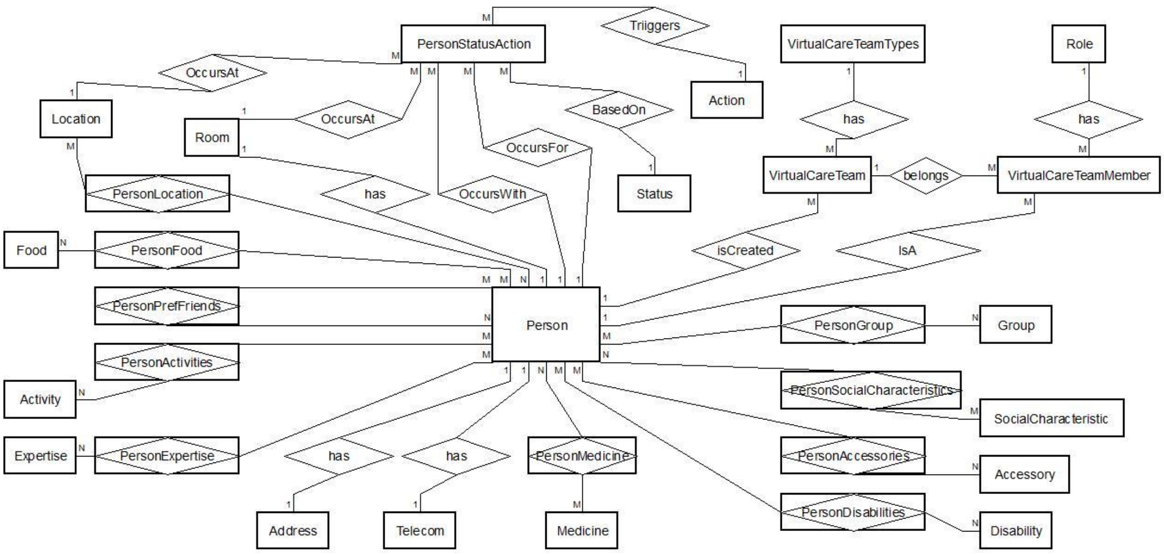

Figure 3. SoCo-net Database Entity-Relationship (ER) schema.

The SoCo-net's Entity-Relationship (ER) database schema is provided in Figure 3. It includes the tables storing Persons' personal information like name, address, telephone number, birth date, email, etc. The Person Profile tables create associations between a Person and his/her preferences related to activities he/she would like to perform, preferences related to the food she/he likes, certain disabilities she/he may have, etc. The VCT tables contain members associated to a specific Person, their roles and so on. A more detailed description of the main tables included in the SoCo-net database is provided in Table 1.

Table 1. Descriptions of the SoCo-net's database tables.

Table Name	Description
Person	*Stores general information about all the users of the system.*
Address	*Stores the information about an address of a Person or a Location included in the system.*
Telecom	*Stores the telecom information of the Person (Prefix, Phone number, etc.).*
Room	*Stores, information about all the rooms that are included in the elderly house.*
Activity	*Stores information about all possible activities a Person may carry out within a day. Such as playing cards, chess, walk in the park, trips, swimming, eating in restaurants, etc.*
Accessory	*Stores information about all possible accessories a Person may need. Such accessories can be eyeglasses, walking sticks, cars, mobile phones, umbrellas, coats, medicine, etc.*
Disability	*Stores a list of all possible disabilities a Person may have (hearing problems, sight problems, walking problems, etc.).*
SocialCharacteristic	*Stores a list of all possible social characteristics that the Person may have. Such social characteristics are for example (does not like water activities, does not like outdoor activities, does not like to see very handicapped people, etc.)*
Expertise	*Stores a list of all possible expertise a Person may have in a certain domain (electrical engineering, doctor, sports, gardening, etc.).*
Location	*Stores a list of all possible locations (specific locations) that a Person may like or do not like to visit (i.e., the park, the hospital, the cinema, etc.).*
Group	*Stores a list of all possible groups that a Person can belong to (i.e., Golf group, Dancing Group, Photograph Group, etc.).*
Food	*Stores a list of different food that can be included in the food menu.*
Action	*Stores a list of all possible actions (call, visit, talk, etc.) a Person would like to perform (or the Social Robot should perform) when the Person is found in a certain status (i.e., depression, sick, pain, etc.).*
Status	*Stores a list of different status (i.e., depression, sick, pain, etc.) a Person might be in.*
Medicine	*Stores a list of all possible medicine that a Person may take.*
PersonStatusAction	*Associates a Person with the specific action that he/she would like perform (or the social robot should perform), the member of his/her VCT he/she would like to perform the action with, and the room that he/she would like the action will take place, in case the Person is found in a certain status (depression, sick, pain, prolong immobility, etc.).*
VirtualCareTeam	*Stores information about a Virtual Care Team (VCT) built around an elderly user.*
VirtualCareTeamTypes	*Stores a list of all possible team types that can be built around the Person (relatives, social workers, friends, neighbours, care professionals, etc.).*
VirtualCareTeamMember	*Stores information about members that belong to a certain VCT and the Role that the members hold in the VCT. A member can be in different VCTs with different roles.*
Role	*Stores a list of all possible roles a member can obtain in a Virtual Care Team (friend, neighbour, daughter, son, caregiver, occupational therapist, etc.).*

One key innovation behind the design and the development of SoCo-net's database is the intelligent management techniques (algorithms) that SoCo-net supports, which dynamically adapt the content, included in the database, throughout the elderly ageing process. These are simple statistical analysis techniques, applied to event logs containing a history of past events and other related history information acquired by the robot through the process of the elderly daily monitoring. Based on event frequency and detected changes, the system can update preferences, VCT member priorities, its routine and so on. Such approach promotes personalized care provision and a means to adapt service provision as the elderly needs change. It aims to keep him/her stimulated and motivated to always retain interest in making use of the SocialRobot services.

Personal data is the core resource that the SoCo-net services are built on. For this reason, security and privacy is an important aspect in SoCo-net, as it is crucial for the users to feel that the system does not allow unwanted privacy intrusions and to ensure that they are in control of the services offered to them. Thus, the key objective is to protect resources through a set of security controls, both preventive and detective. The most prominent aspect is that only authorized users may access and use sensitive data or invoke services. Also, the associated database server is installed and accessed using secure web protocols.

2.5 Robotic Platform built-in Functional Capabilities

The functionalities implemented in the platform are exposed to the workflow engine as ROS Services. They are categorized into perception, navigation, data communication (Comm.) and interaction. In Table 2 we present their descriptions. A service emerges from a combination of different available functionalities that accept dynamic parameters, which are mainly obtained from the perception and interaction categories.

The previous section described how the robot executes each of these functionalities, providing thus a service to the elderly. Each of these functions is composed of different low-level methods which interact with hardware and the database. Unlike Services, the platform Functions have not been defined as XML. The fundamental reason is that the number of low-level methods is significantly higher than those of the functions and an XML definition would be far too complex to make it a viable solution. Moreover, method definition and understanding requires high technical knowledge, reason for which a detailed manual exists for developers to code their functions from a wide range of existing methods.

3. SERVICE PERSONALIZATION AND ADAPTABILITY

Existing robots are built to provide limited services which have been programmed *a priori*, upon analysis of end-user group requests. It is virtually impossible to pre-define a service that will be capable to continuously fulfil elderly people's needs throughout their ageing process, mostly because these needs are constantly changing. Exception made to services that are most commonly offered by service platforms in elderly care, such as monitoring and reminding.

Table 2. Implemented SocialRobot platform functions.

Development Category	Function	Description
Perception	**Face_recognition**	Captures an image from the available vision devices identifies the face of the person in front of the robot. Can detect multiple faces and is based on the ROS face recognition package.
	Emotion_recognition	Records audio and identifies a set of different emotions. It is based on the opensource *OpenEar* software [Eyben, Willmer and Schuller, 2009].
	Object_recognition	Capability of recognizing objects. **Experimental phase only.**
	Word_spotting	Using CMU *PocketSphinx* software, we are able to robustly recognize 20 different words, in a semi-controlled sound environment.
	Gesture_recognition	Capability of recognizing 5 different hand gestures and 5 body movements to interact with the robot. **Experimental phase only.**
Navigation	**Go_to**	Using the ROS navigation stack, the robot goes to specific locations in the environment. It requires a model of the environment, where real time data detects changes and updates the existing model.
	Person_tracking	Using the ROS Openni2 stack we can detect body skeletons whose data is used to control the navigation for appropriate interactive robot pose.
	Patrol_location	Given a map of the environment, the robot uses an optimized patrolling strategy to go around the environment.
Comm.	**SoCo-net_call**	Set of functions responsible for accessing and managing the elderly information located in the SoCo-net database.
Interaction	**Speech_synthesis**	A database of pre-defined speech recording is used by to robot to verbally interact with the user. The voice and tone are selected according to specific parameters.
	Information_display	Module responsible for displaying relevant information in the tablet interface, e.g. agenda or calendar.
	Social_connection	We use a Skype interface to establish remote communication between the elderly and members of the VCT. In the future will support SMS messaging system.
	Dialogue_management	Uses the above modules to orchestrate an intelligent dialogue with the user to efficiently execute a service according to elderly needs.

Consider a scenario where such a system is deployed in a multi user environment. Under the current paradigm, the same service will be repeated over and over again, which reflects in a decrease of user acceptability and loss of interest in using the platform.

Additionally, these platforms usually operate on request, which means that the user is often the party responsible for initializing the interaction process. By exploiting personal information, we propose an active service providing strategy which is best explained through a simple example scenario.

***Concept Scenario**: (...) Now with the presence of the Social Robot, half an hour before the meal, Social Robot considers the menu and the meal preferences of each elder. By comparing the menu and the meal preferences of Andreas, Marios and Antonis, Social Robot noticed that Andreas does not like the menu but Antonis and Marios love it. SocialRobot goes to the room of Andreas, Antonis and Marios to inform them about the menu, and save Andreas from walking in the eating room and also remind Antonis and Marios not to skip the dinner because the food today is their favourite. The three men were discussing that the care staff is so overloaded with the more severe sick people in the centre, that they always ignore them thinking that they can still do most of the things alone and that only Social Robot looks for them. (...)*

The presented solution to solve this scenario maximizes the exploitation of the information in the database. Preference and priorities for different persons allow each user to have an engaging and personalized experience with the robot, which is different from all the others because it satisfies their personal needs based on their own preferences and behavior profiles [Santos, Christodoulou and Dias, 2014]. In Table 3, we have a clear example of how the described scenario can be parameterized into services and which functions are required to complete it.

Table 3. Breakdown of the use-case scenario in terms of required services and functions.

Concept Scenario Parameterization	**Required Service**	**Functional Capability**
(...) Now with the presence of the Social Robot, half an hour before the meal, Social Robot considers the menu and the meal preferences of each elder. By comparing the menu and the meal preferences of Andreas, Marios and Antonis, Social Robot noticed that Andreas does not like the menu but Antonis and Marios love it.	***Daily Routine monitoring and assistance***	***1. Preference Assessment*** ***2. Task Guidance***
SocialRobot goes to the room of Andreas, Antonis and Marios	***Robotic***	*1.* ***Localization*** ***2. Navigation***
to inform them about the menu, and save Andreas from walking in the eating room and also remind Antonis and Marios not to skip the dinner because the food today is their favourite. The three men were discussing that the care staff is so overloaded with the more severe sick people in the centre, that they always ignore them thinking that they can still do most of the things alone and that only Social Robot looks for them. (...)	***Human-Robot Interaction***	***1. Face Recognition*** ***2. Speech Analysis*** ***3. Speech Synthesis***

One of the major challenges concerning our proposed architecture solution is the learning phase, which is the problem of associating preferences and priorities to a specific person. Presently, as already mentioned, this information is supervised by members of the elderly VCT or obtained from elderly feedback during the interaction phase. One key innovation of this approach is that the database can be accessed remotely and has a friendly user front-end allowing credentialed members of the VCT to manage this information along time. Moreover, the robot by itself maintains a history of information, which from time to time it uses to automatically update the Person Profiles, *e.g., frequently attended activities will gain priority over others.*

Platform Usefulness and Longevity: The proposed architecture modularity clearly benefits the longevity of the platform. In fact, methods and functions can be seamlessly replaced to cope with the scientific research and technological advancements. The integration of new modules only needs to ensure compliance with the defined communication input/output message structures.

Example*: Let the system have an operational module for identifying faces based on Method 1, whose input is an Image and the output a String with the name of the identified person. Let a new Method 2 be developed, which is able to provide better identification results. A developer's only concern needs to be the encapsulation of Method 2 such that the input/output pair is still an Image and a String and that the encapsulation requests and publishes such information in the correct message topic.*

This example illustrates how this strategy will, at least, prevent the platform from being easily outdated, maximizing thus a long and useful existence at an elderly home. Exploiting the proposed paradigm, we aim to go one step further in the way service robots interact and assist the elderly. An intelligently managed database is presented, where elderly information and profiles are exploited for personalized service provision.

4. INITIAL PRATICAL EXPERIMENTS

Our experimental assessment and validation is currently divided into two different stages: 1) testing of the different functionalities of the system, as well as their integration using ROS; 2) performance of two simple use-case scenarios (A and B) tested in an office controlled environment, with limited sound sources because of speech recognition and a controlled environment layout, without significant changes for better navigability. The layout is illustrated in Figure 4.

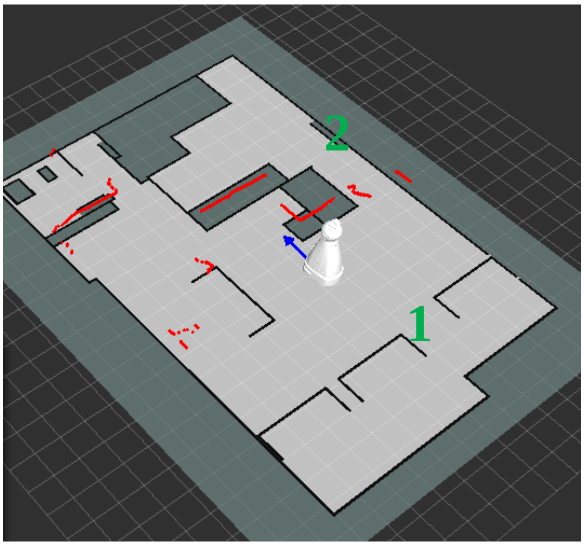

Figure 4. Map of the environment where the first experiments have taken place.

The environment is mainly divided into two conceptual areas, public (Zone 1) and private (Zone 2), where the latter simulates an elderly quarters. Based on such layout, two scenarios have been devised, which allow evaluation and exhaustively testing of different functionalities and the execution engine.

4.1 First Experimental Use-Case Scenarios

Table 4. Description of the experimental use-case scenario A divided into functional steps.

Scenario Description Parameterization	**Callback Function**
The robot is doing is regular walk around by elderly rooms, and stops at Mrs. Johnson's.	`Go_to`
It carefully approaches her	`Person_tracking`
in order to recognize her and confirm her presence in the room.	`Face_recognition`
Then, the SocialRobot asks her: "How is your day going Mrs. Johnson? Is everything ok?"	`Speech_synthesis` `Word_spotting`
The robot will wait for her to respond, and from her voice response the robot will infer about her emotional status.	`Emotion_recognition`
According to the detected status, SocialRobot will make a suggestion, which can be one of four different outcomes (described bellow).	`SoCo-net_call:` `Suggestion`
After their interaction, SocialRobot will resume its walk around.	`Patrol_location`

The described scenario A in Table 4 considers four possible outcomes for a given user, which depend on the detected emotional status and of the information and preferences contained in the SoCo-net. In the specific case of Mrs. Johnson, if she is found *sad*, she will be suggested to call her daughter. If she is *bored*, SocialRobot will suggest her to participate in one of her favorite activities. In the event it detects a *fear* or an *aggressive* response, SocialRobot will alert a responsible VCT member to take appropriate actions. Finally, if Mrs. Johnson is *happy*, the robot will let her enjoy the rest of her day resuming its walk around task, letting her know that it will be available if needed.

Regarding use-case scenario B (see Table 5), it was designed with the purpose to demonstrate the active role of the SocialRobot platform while performing common tasks, such as reminders. The robot will be performing a monitoring walk around the centre, and when it detects a person, it will use navigation to position itself correctly in order to interact with the elderly. It will recognized the person and check that person's activity and medicine agenda available from SoCo-net using a 30 minutes window frame. In case it detects an event that is due in the previous half an hour it will let the elderly know, while simultaneously warning a responsible care giver so that appropriate measures may be taken. On the other end, if the event is due in the next half an hour, it will issue a friendly reminder such that the elderly does not forget it. There might be cases where there are no events to report and the robot will resume its regular walk around.

Table 5. Description of the experimental use-case scenario B divided into functional steps

Scenario Description Parameterization	**Callback Function**
The SocialRobot is taking its usual walk around the centre	`Patrol_location`
when it crosses an elderly in the hall	`Person_tracking`
and by using its face recognition, it recognizes Mrs. Johnson.	`Face_recognition`
As usual, when randomly meeting elderly, the SocialRobot will check the SoCo-net for the activity and medicine agenda. It sees that Mrs. Johnson had to take her diabetes pills a few minutes ago.	`SoCo-net_call: Agenda Checking`

It asks her: "Mrs. Johnson, did you take your diabetes pills?" She answers "No, I forgot." By recognizing the word "No" the robot replies "You should take them now and I will let Joan (the caregiver) know, to see if anything else is needed." The platform sends a warning to Joan, which in 2 minutes will come to check upon Mrs. Johnson.	`Speech_Synthesis`
	`Word_spotting`
	`SoCo-net_call: VCT member warning`

The SocialRobot then resumes its walk around.	`Patrol_location`

We have performed over 40 trials of the proposed two use case scenarios. Facial and emotion recognition have a combined accuracy of over 82%. In addition, service execution completes successfully most of the trials, where only a sample residue (3 in total) of all performed tests have been interrupted due to technical and/or recognition failures.

In terms of navigation, the robotic platform has a 60cm safety distance from objects. The existence of a pre-defined map allows it to navigate while avoiding obstacles. The map is continuously updated with new information, using real time sensor data to maintain a current map version. Navigation is supported by the RGB-D data, in order to complement the laser range finder readings and detect obstacles where the laser is not so efficient, such as tables, etc.

Interaction uses basic word-spotting combined with yes/no questions. The *PocketSphinx* toolbox exhibited over 90% recognition rate in detecting between the *yes* and *no* responses, which made interaction fluent and accurate. Moreover, in cases where emotion and facial recognition did not meet the required confidence threshold, the robot would request explicit confirmation, for which these results are even more significant. For example, the SocialRobot will verify an unconfirmed emotion recognition with a question like "*Are you sad Mrs. Johnson?*"

One very important aspect is that, at any instance, if the user starts to feel uncomfortable with the robot, it may shut it down by pressing a big red button, located at the back of the platform. At this instant, the robot will launch an alert to the relevant members of the VCT, warning them that it will be disconnected and that they need to take the appropriate preventive measures. After this safety procedure, the robot goes to its base station and shuts down.

4.2 Future Experimental Validation

After the laboratorial assessment, the first pilot-trials are already being prepared. End-user involvement continues to be a priority; hence the programmed exploitation activities using the proposed scenarios are being closely accompanied by the end-user institutions and real users. The main outcome of these activities is twofold: 1) to assess end user acceptance of the robot while executing services; 2) verify that the obtained success in laboratory scenario execution is transferred when operating in real environments. One particular concern within user acceptance is to evaluate to what extent the users feel they are always in control of the operations. To get such feedback, after a battery of tests we will ask users to fill a questionnaire. The goal is to get the feedback about increased motivation and reduction of hesitations in carrying out their daily routine with the support and company of the SocialRobot platform. Previous questionnaires have been conducted to design and develop a platform outer shell, resulting in a robot that users find friends and fun to interact with. The tests will occur simultaneously with the forthcoming project's review meeting, with special invitations to interested end-users. Their participation in the tests of this preliminary scenario aims to attract both research and industrial stakeholders and promote know-how transfer in the projects technology and results at a European and an international level, so as to define a market penetration strategy. The invited end-user institutions will be explained the modularity of the system and promote a discussion of other use case scenarios that can be solved using our proposed architecture. Results and videos will be available in the project's official website http://mrl.isr.uc.pt/projects/socialrobot.

5. CONCLUSIONS

This manuscript presented a development strategy for a modular architecture of a service robot, targeting a societal and economic impact. We argue that this abstraction strategy between different conceptual layers, will allow the system to be constantly and seamlessly integrated with new functionalities and devices. The nature of the service design, using an XML structured description, allows new services to be composed and tested in short time. In fact, it provides an intuitive and fast way to add new servicing capabilities to a robot so as to fulfil new elderly requirements, while simultaneously cope with the technological and scientific advancements, requiring only a set of simple restrictions. This means that when acquiring an expensive robotic platform, one knows in advance that it can be easily extended without additional high costs. The system evolves its capabilities during its lifelong durability. In order to better provide personalized assistance, the system encompasses a database of personal information which is intelligently managed. This is also a key aspect in the proposed system, because it means that behaviour profiles and preferences of a user can be synchronized with current elderly conditional status. Consequently, the system is capable of adapting its services accordingly, thus easing the take up of this technology by an elderly as being its own, because of the empathic and personalized assistive interaction. In addition, a continuous (timely) analysis of elderly information allows the robot to actively engage a user, which extends its assistive usability. We conclude that the presented concepts and discussion constitute an alternative, appropriate strategy for developing new service robots which will have a longer and efficient lifelong usability. The implemented platform has been tested in laboratory with success and end-users are very stimulated to start the pilot trials with the friendly SocialRobot platform.

ACKNOWLEDGEMENT

This work is supported by the Social Robot project, funded by the European Commission within the FP7, by People Programme, Industry-Academia Partnerships and Pathways (IAPP), under grant agreement 285870.

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